BODY ENGINEERING
COURSE WORK ON
AERODYNAMICS OF A SPORTS COUPE

Deepak Lalit Gupta
M.Sc. Automotive Systems Engineering
Department of Aeronautical and Automotive Engineering
Loughborough University
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Executive Summary

This coursework reports aims at presenting the method and findings of the study conducted to understand the aerodynamics of a sports coupe. A scaled model was tested in a wind tunnel and data required for calculation of aerodynamic coefficients of drag, lift and pitching moments was collected. The first test involved studying the variation of these coefficients with the change in Reynolds number. It was observed that above the value of critical Reynolds number of $0.5X10^6$ the coefficients can be considered to be independent of the Reynolds number. To understand the relation between the yaw angle and these coefficients, data was recorded for yaw angles up to 30 degrees. An increase in the value of lift and drag coefficient is seen due to separation occurring on the opposite side, however some reduction is observed with the use of a front spoiler. To understand the flow field around the vehicle centreline pressures are recorded over the surface. Majority of the drag component is seen to be contributed by the suction at the rear end of the vehicle. The normal pressure coefficients are calculated based on the centreline pressure readings dividing the vehicle into suitable areas and are used to find the normal pressure drag coefficient. It is observed that the change in coefficient of drag between base and spoiler configuration is not same for the readings taken using tunnel balance and calculated using the normal pressure coefficients. This variation is because the pressures are measured along the centreline and not across the entire surface, thus giving misleading results. In conclusion, the coursework helped in realising the importance of scaled model testing in giving fairly representative results and understanding of the flow field with considerably less efforts and resources as compared to full scale model testing.

1. Reynolds Test

The coefficients of Drag, Lift and Pitching Moment are plotted against Reynolds Number in figures 1.1 and 1.2 respectively.

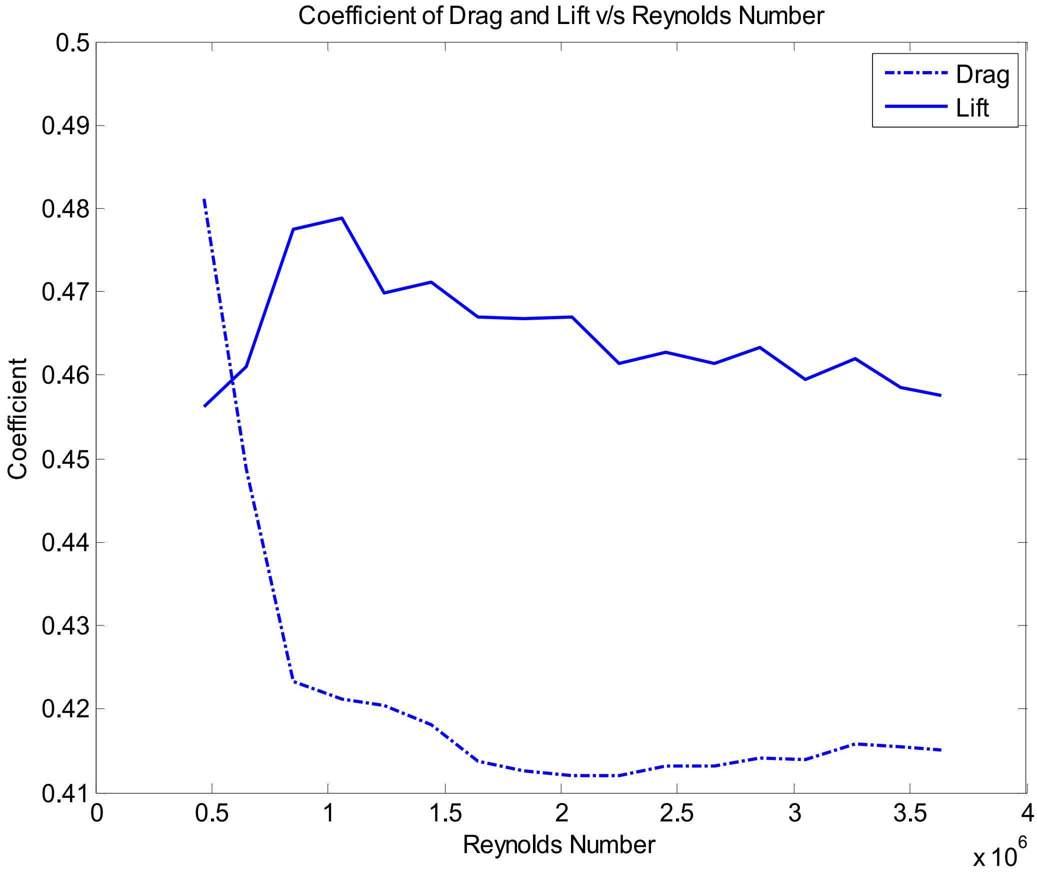

Figure 1.1: Coefficient of Drag and Lift against Reynolds Number

As seen from figures 1.1 and 1.2, the coefficient of drag (C_d) and pitching moment (C_{mp}) vary within the Reynolds number range of 0.5 x10^6 to 1x10^6. It is seen that C_d decreases sharply around critical Reynolds number of 0.5x10^6 as this is the number where **boundary layer transition** is most likely. For higher values of Reynolds number it is seen to be independent.

Two main considerations while testing with scaled models are the **geometric similarity** and **mechanical flow similarity**. High degree of geometric similarity is not easy to achieve with small scale models, and may not always be necessary as well. However, a considerable amount of geometric detail which has a significant effect on the flow field around the car is necessary to be included. Mechanical flow similarity refers to ensuring that the Reynolds number for scaled and full scale model is same. This requires the product of the velocity of the medium and the characteristic length of the model to be same, for same flow medium. The Reynolds number range in the test exceeds the critical Reynolds number and the flow field around the scaled model is similar to that of the full scale. Also as the **model** used is suitably **similar** in terms of geometry of the full scale model, it can be concluded that the results for aerodynamic coefficients will be representative of the full scale.

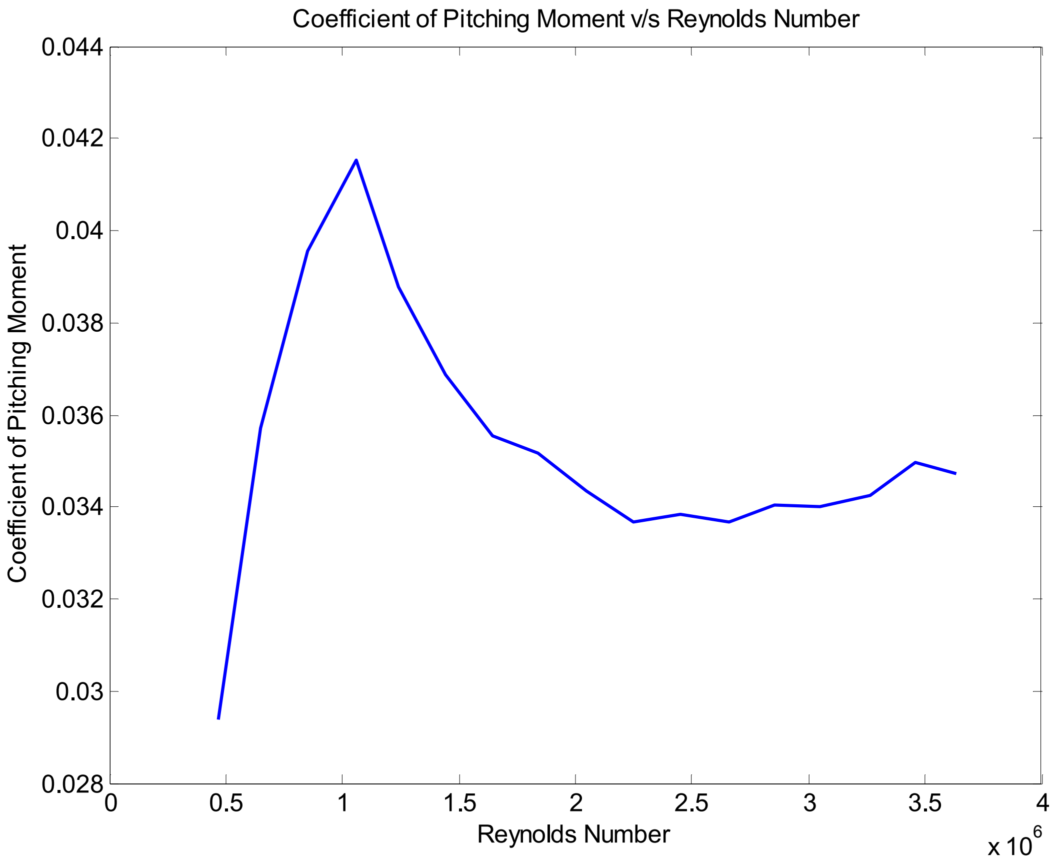

Figure 1.2: Coefficient of Pitching Moment against Reynolds Number

2. Yaw Sweep

Figure 2.1 shows the variation of aerodynamic coefficients with respect to yaw angle. It is observed that all the coefficients are symmetric for either side of the vehicle. Significant rise is seen in the drag and lift coefficients as the angle is increased.

A **pressure differential** between the top and bottom of the vehicle causes a lift force. As the yaw angle changes away from zero, a significant increase is seen in the pressure differential is between the **upper and under side** of the car. This **increases the lift coefficient** which can take values higher than 1.

In crosswind conditions, an asymmetrical flow field around the vehicle is present. This leads to an **asymmetric pressure distribution** causing a lateral force and a yawing moment, which can be reduced to side forces at the front and rear axle of the car. Also due to asymmetric pressure distribution, flow is attached well to the wind side of the body and **separation occurs on the opposite** side. A significant **drag component is added** to the vehicle due to this separation. A change of 15% is seen in the drag coefficient between 0 and 20 degrees of yaw angle. The difference in pressure on the wind side and the opposite side also produces a **rolling moment R**. However the effect of the rolling moment is comparatively limited.

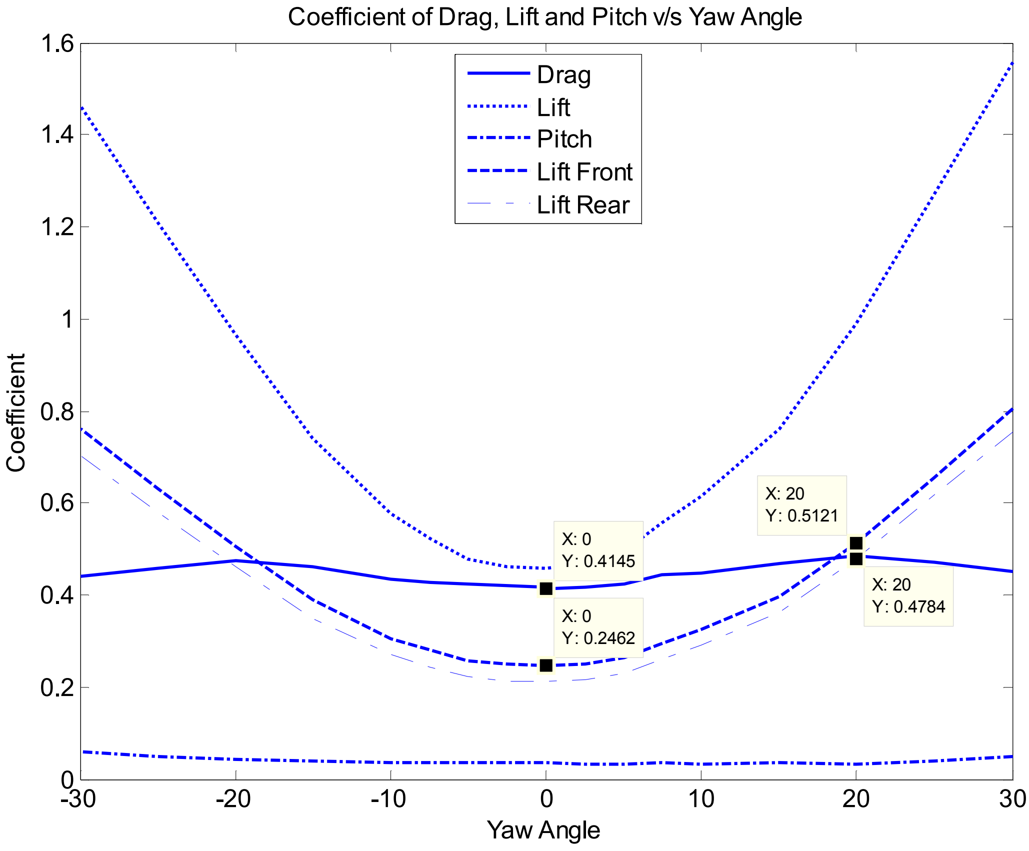

Figure 2.1: Coefficient of drag, lift, pitch and front and rear axle lift v/s yaw angle for base vehicle

The pitching moment is said to act to transfer the weight between the front and rear axles. Pitching moment is most sensitive to the angle of attack of the vehicle and hence is not affected much by the yaw angle as can be seen from figure 2.1 and 2.2. However, combined effect of the lift and pitching coefficient is used to calculate the front and rear lift coefficients, and it can be seen that the lift force at the front axle is greater than the rear axle.

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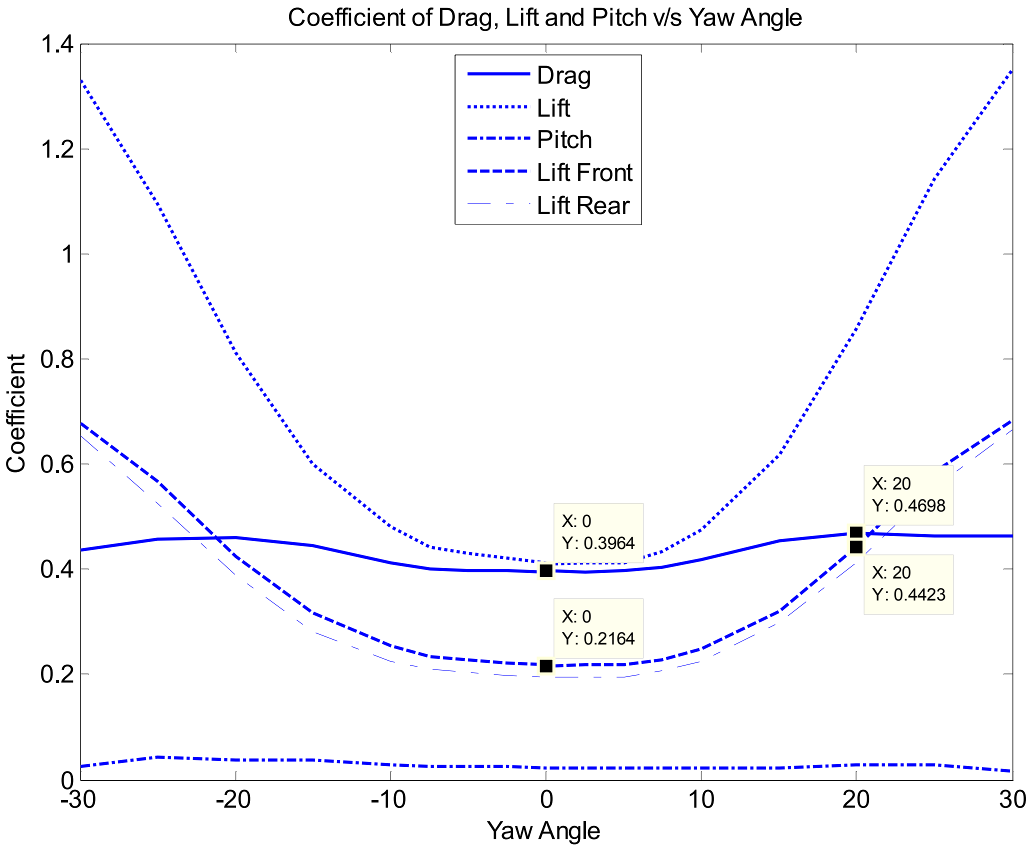

Figure 2.2: Coefficient of drag, lift, pitch and front and rear axle lift v/s yaw angle for vehicle with spoiler

In the base configuration, the local velocity of the flow is higher than the free stream, and hence a positive pressure region is formed under the car. This combined with the suction above the car produces a lift. An increase in front lift coefficient decreases the steering controllability. A front spoiler reduces the lift force on the front axle by limiting the increase in the velocity of the air going underneath the car, thereby reducing the suction in that region and helps in maintaining control. **The front lift coefficient is reduced by around 15% with the introduction of the spoiler.**

Increment in drag coefficient is mainly because of the separation on the opposite side, which is not affected by the introduction of a spoiler. However, the drag contribution by the front section of the vehicle is reduced by the spoiler.

The comparison is tabulated below.

	Base Vehicle		**With Spoiler**		**Reduction**
Angle (degree)	0	20	0	20	
Drag	0.41	0.47	0.39	0.46	approx 5%
Front Lift	0.24	0.51	0.21	0.44	approx 15%

Table 2.1: Comparison of drag and front lift coefficients for base and spoiler configurations

3. Pressure Distribution

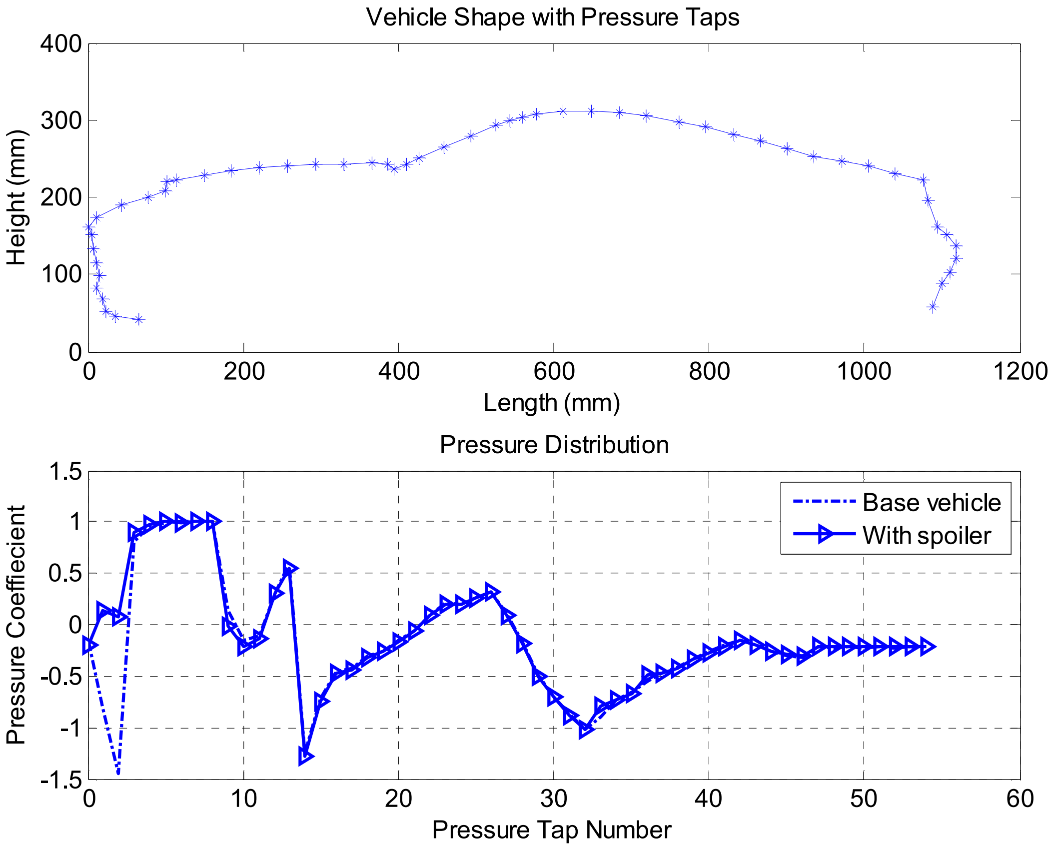

Figure 3.1: Centreline Pressure Distribution for Base vehicle and With Spoiler

It is seen for the centreline pressure distribution, when it is plotted against the pressure taps that a negative Cp is developed at the underside of the bumper in the base vehicle as the local velocity is higher than the free stream. With the use of a spoiler, this acceleration of air under the body is controlled and a **suction region is avoided**.

At the front of the vehicle, a **stagnation region** exists as the local velocity becomes zero and Cp = 1 for this region. In this region the **flow separates** to move over and under the vehicle. A **pressure drop** is then seen at the front end of the **hood** as the flow rising over the front of the vehicle attempts to turn and follow horizontally along the hood. A small **upward contour** is seen in the **hood**, and a **local region of separation and reattachment** is developed dropping Cp to a value below -1. An adverse drop in pressure is seen due to acceleration of the flow over the rising shape.

The pressure steadily **recovers** till the end of the hood and the **start of the windscreen** due to the drop in the local velocity. As the flow rushes up the windshield, the velocity is again increased and the pressure drops. The pressure is negative over the roof as the flow tries to follow the roof contours. Towards the end of the roof, some pressure is recovered and it is in this region that separation can occur.

At the rear end, the flow along the sides is drawn into this low pressure region combining with the flow over the roof to form vortices. A well ordered steady three dimensional flow separation is seen at the rear. However this **separated flow induces suction** which leads to pressure drag. Hence, a major contribution in the overall drag for the vehicle is from the rear end. The point of separation plays an important role in defining the suction at the rear end.

4. Pressure Distribution Normal Pressure

The normal pressure drag coefficient for the vehicle in the two configurations is calculated using the centreline pressures. The surface of the vehicle is divided into 6 sections in all. The first 4 contributing to the front pressure coefficient and the last two to the rear pressure coefficient. A summary of the assumptions made is given in table 4.1.

Area	Pressure Tap		Height (mm)		ΔHeight(mm) (absolute)	Mean Cp	
	Start	End	Start	End		Base	Spoiler
Front 1 (Bumper)	1	10	41	161	120	0.15	0.26
Front 2 (Hood)	11	24	173.8	243.4	69.6	-0.04	-0.05
Front 3 (Windscreen)	25	32	235.7	304.3	68.6	-0.04	-0.04
Front 4 (Roof)	33	35	307.6	311.6	4	-0.01	-0.01
Rear 1 (Rear Window)	36	47	309.7	221.5	88.2	-0.13	-0.13
Rear 2 (Rear Bumper)	48	55	196.5	58.1	138.4	-0.13	-0.12

Table 4.1: Assumptions and distribution of surface area

The results in comparison with that obtained from the tunnel balance are tabulated in table 4.2.

	Tunnel Balance		Pressure distribution	
	Base	Spoiler	Base	Spoiler
Cd	0.41	0.39	0.32	0.42
Δ Cd	0.02		-0.10	

Table 4.2: Tunnel balance and pressure distribution comparison

From the above comparison it is evident that the value of **ΔCd differs** significantly between the two methods of calculation of Cd. This difference is mainly because of the way in which the pressure is measured for the calculation of normal pressure distribution. The **pressure taps** are located at the **centre of the surface** area and hence do not give an accurate value of the pressure distribution over the entire area. Using these values, the Cd calculated cannot be considered accurate. On the other hand the Cd obtained using the tunnel balance is more accurate as it accounts for the pressure distribution on the entire surface of the vehicle.

The values obtained for Cd using the centre line pressure distribution may not be accurate to calculate the overall drag coefficient, but it can be used to get an insight into the contribution to the overall drag by different sections of the vehicle. It can be seen from table 4.1 that the mean pressure from the front bumper is almost equal to the combined contribution from the hood, windscreen and the roof added together, but in the opposite direction. In other words, the **pressure drag** created by the **front bumper** is almost **balanced by the suction** over the hood, windscreen and roof.

In total drag of 0.32, the rear section contributes as high as 0.26. Hence it can be said that the rear section of the vehicle contributes almost 75% of the drag.